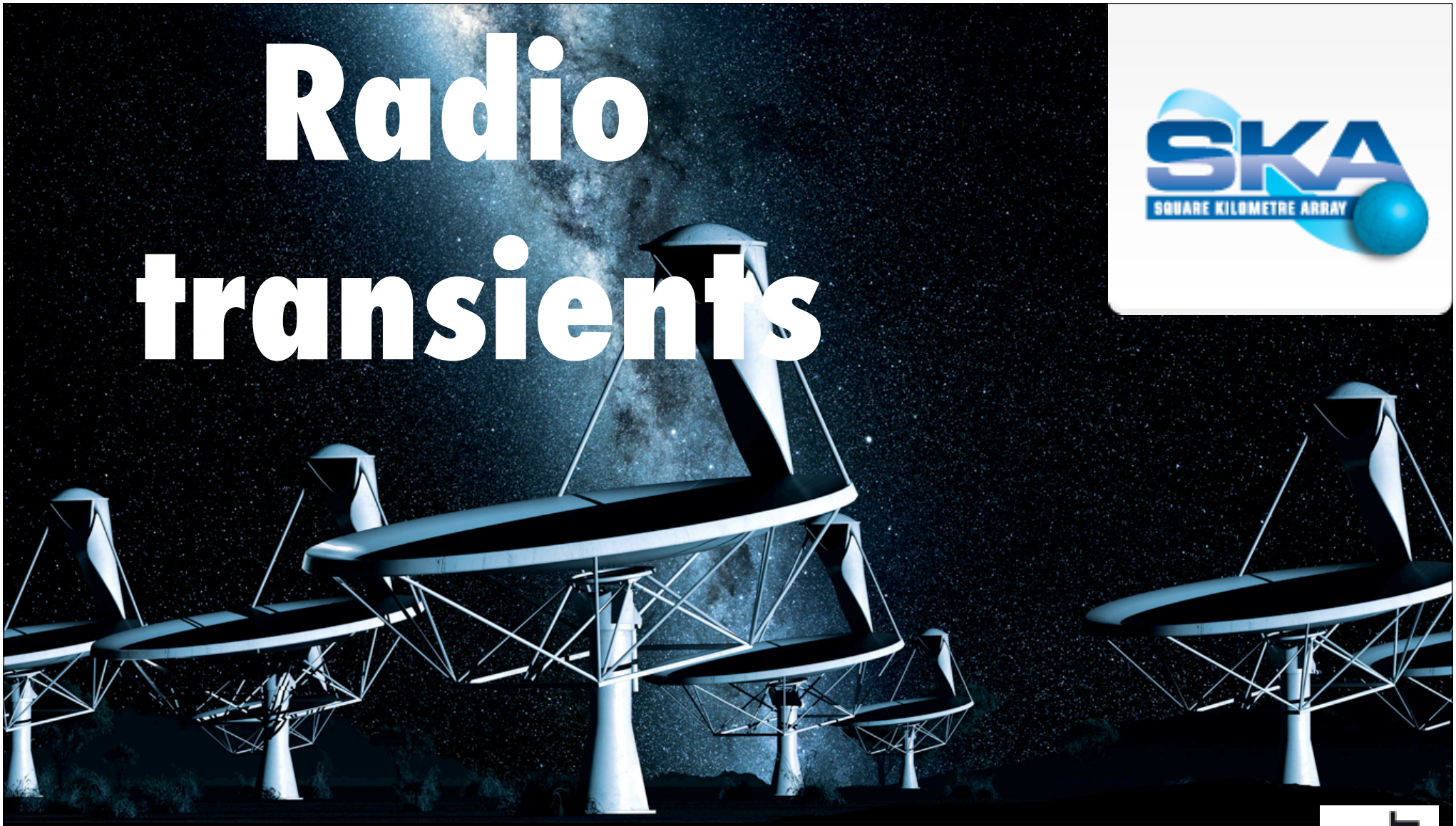
Radio transients



SKA
SQUARE KILOMETRE ARRAY

Stéphane Corbel

Univ. Paris Diderot & CEA/IRFU/SAp & IUF

AIM

LabEx UnivEarthS

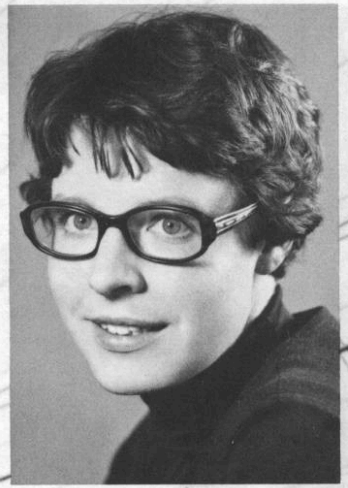
université PARIS DIDEROT PARIS 7

Why transients ?

The transients radio sky

- A glimpse of physics in extreme environments.
- Time domain astronomy: a huge discovery potential, recognized in all recent prospective reports. Testing relativity. Cosmic lighthouses for probing the IGM.
- Example of unexpected transients: Discovery of pulsar by J. Bell (Nobel for Hewish), SN1a, GRB, ...
- Even now, new type of transients are still discovered nowadays: TDEs and FRBs
- A huge variety of transients on very different timescales: X-ray binaries, pulsars, black holes at cosmological distance, atmospheric γ-ray flashes, exoplanets, EM signature of GW, the unknown, ...

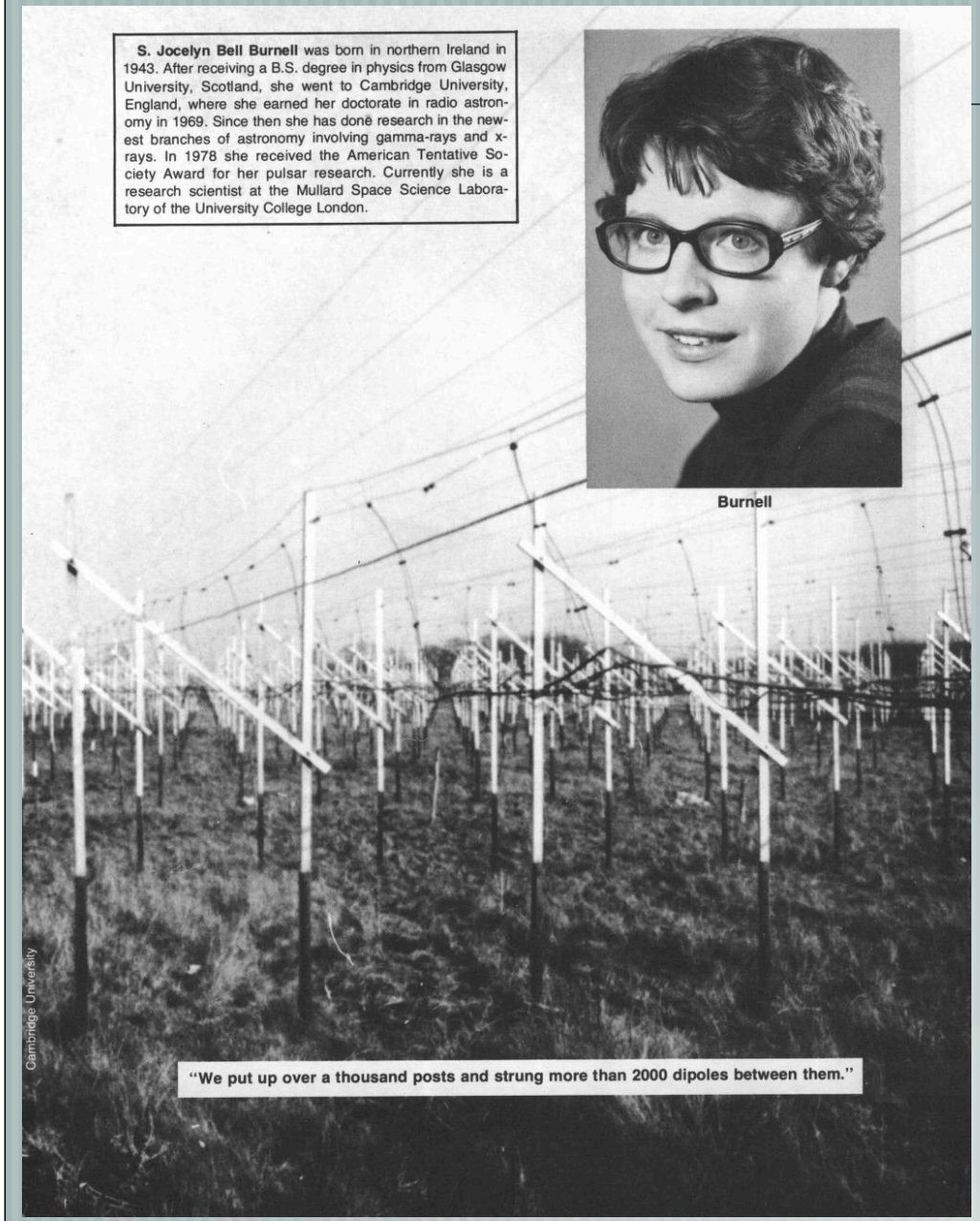
S. Jocelyn Bell Burnell was born in northern Ireland in 1943. After receiving a B.S. degree in physics from Glasgow University, Scotland, she went to Cambridge University, England, where she earned her doctorate in radio astronomy in 1969. Since then she has done research in the newest branches of astronomy involving gamma-rays and x-rays. In 1978 she received the American Tentative Society Award for her pulsar research. Currently she is a research scientist at the Mullard Space Science Laboratory of the University College London.



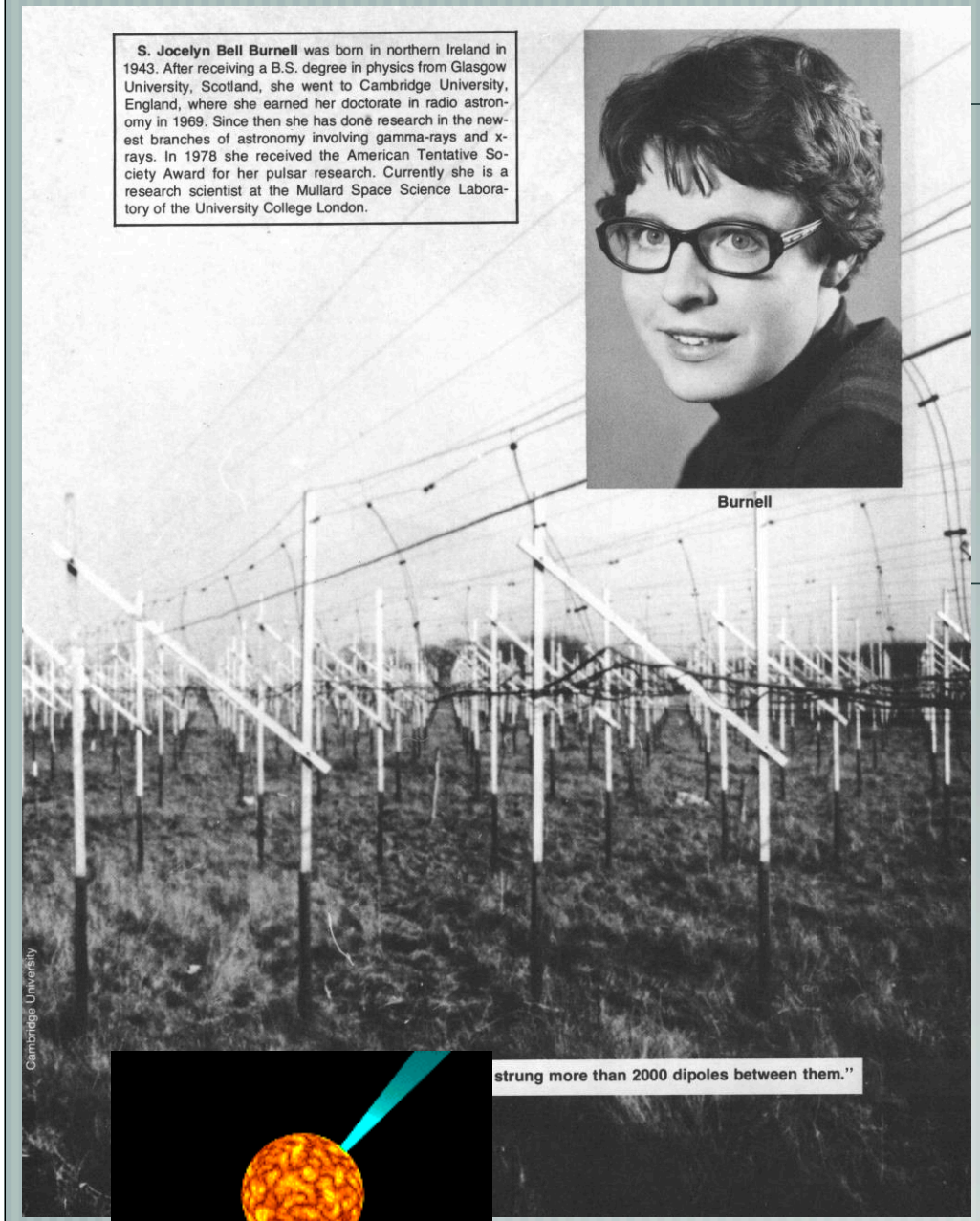
Burnell

Cambridge University

"We put up over a thousand posts and strung more than 2000 dipoles between them."



The Mullard (Cambridge) telescope was built to measure interplanetary scintillation (for quasars)



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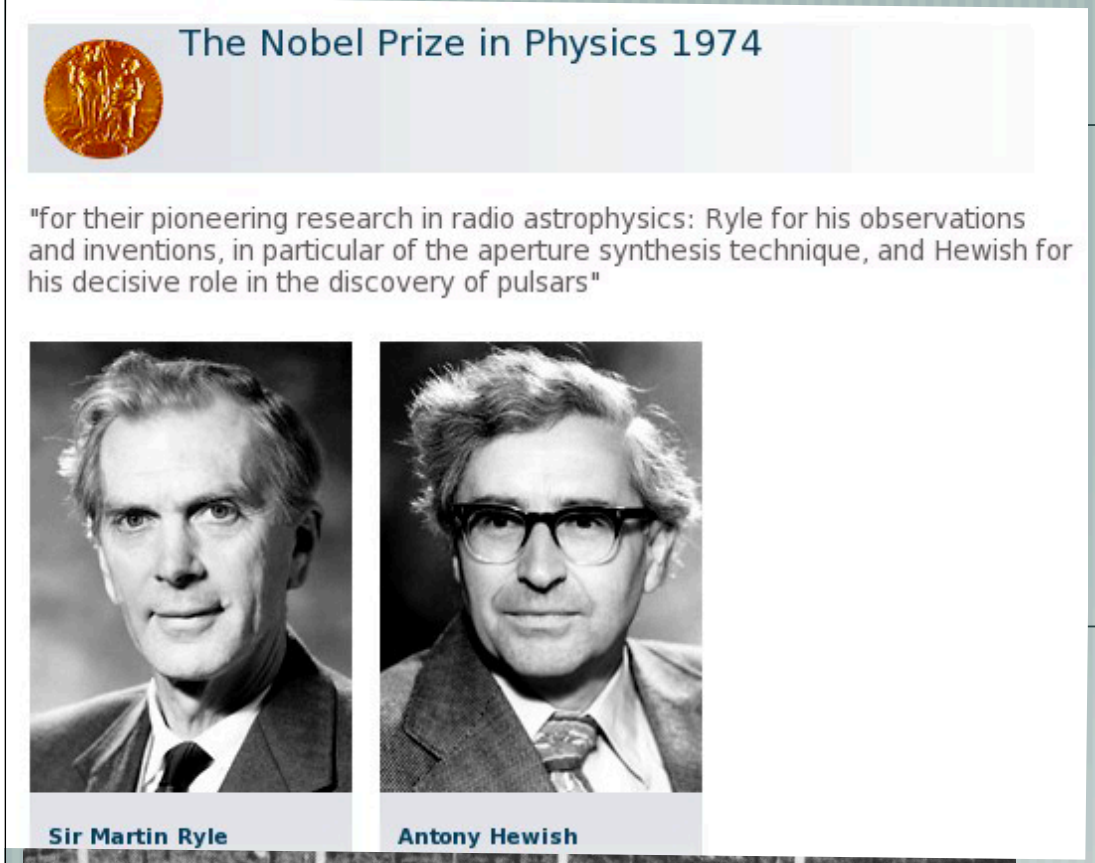
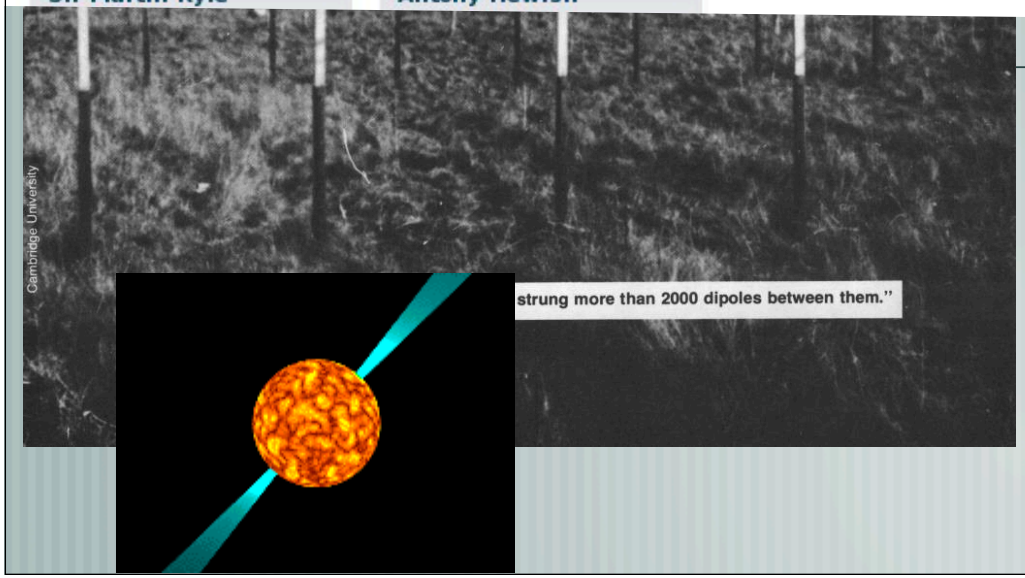


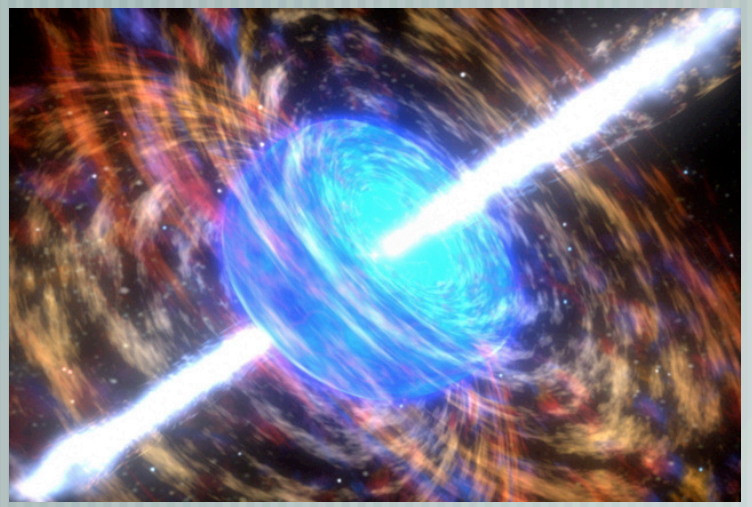


- The Mullard (Cambridge) telescope was built to measure interplanetary scintillation (for quasars)
- It lead to the discovery of **pulsars** by J.Bell
- but the 1974 Nobel prize to Hewish (pulsar) and Ryle (aperture synthesis)

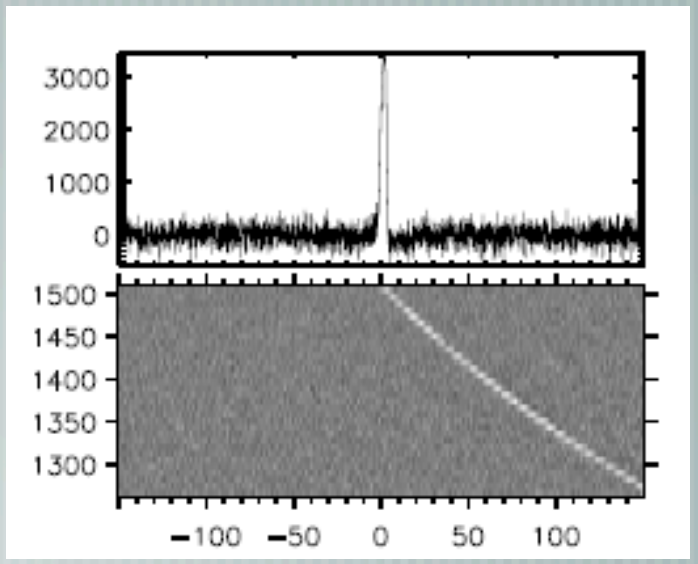
Two flavours of transients

- **Incoherent** synchrotron emission
  - Relatively slow variability
  - Brightness temperature limited (10^{12} K)
  - Associated with all explosive events
  - Strong potential for MW astronomy

- **Coherent** emission
  - Relatively fast variability
  - High brightness temperature
  - Often highly polarised
  - Usually associated with pulsars ?

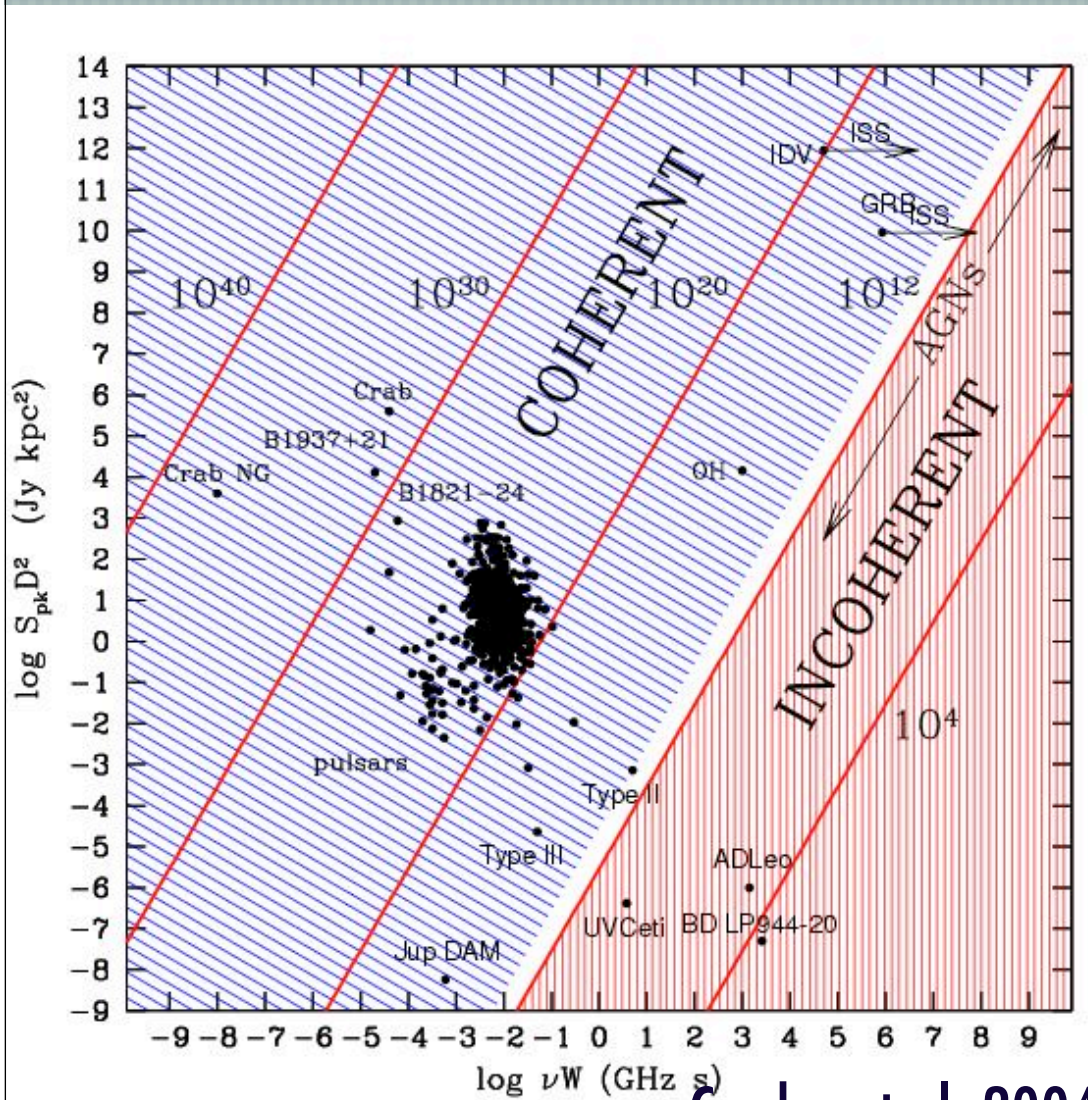


Detection: images



Detection: time series

Transients parameter space

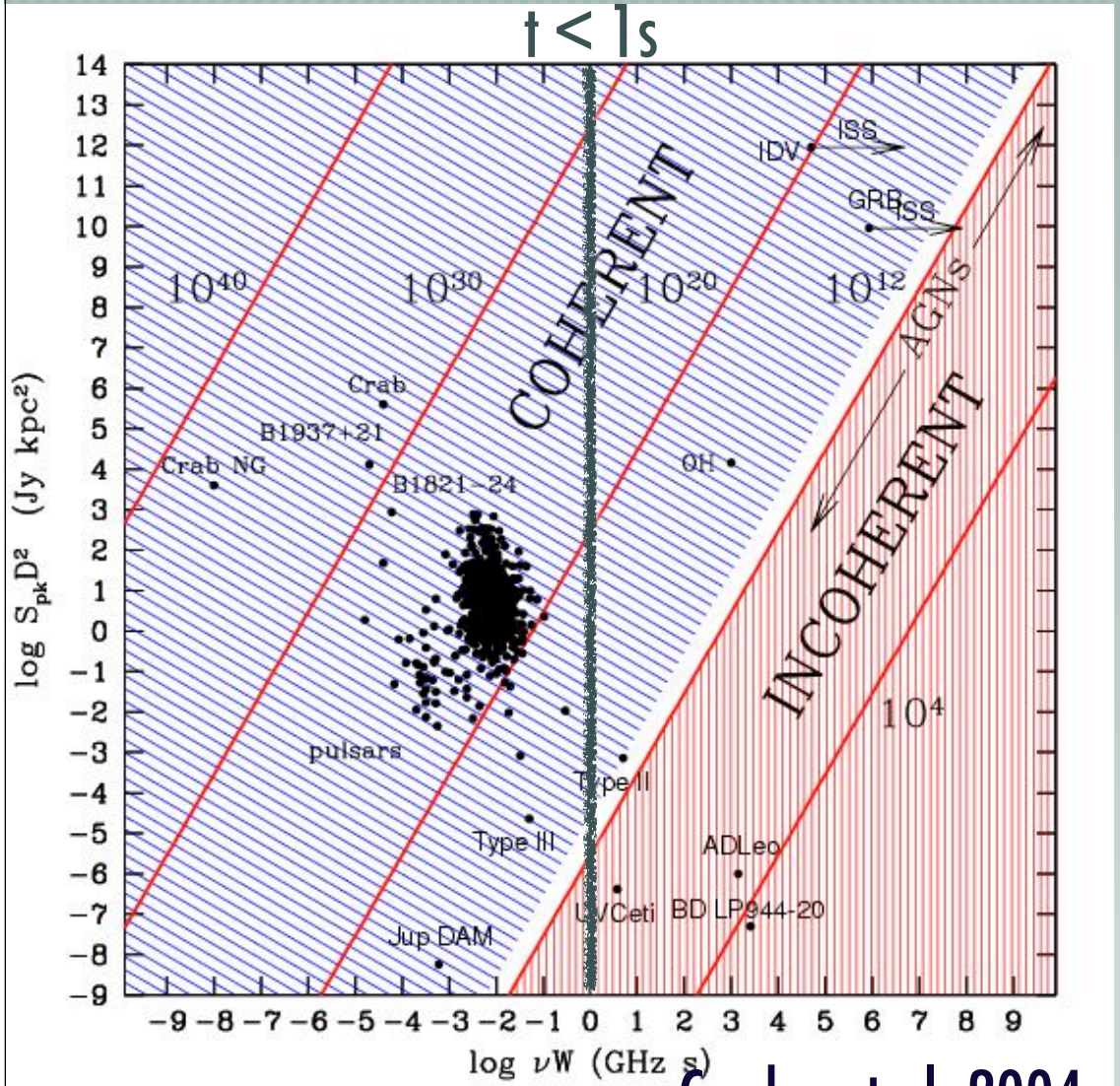


Cordes et al. 2004

$$(W\nu)^2 \propto S D^2/T$$

Parameter space largely empty and unexplored !!!

Transients parameter space



Cordes et al. 2004

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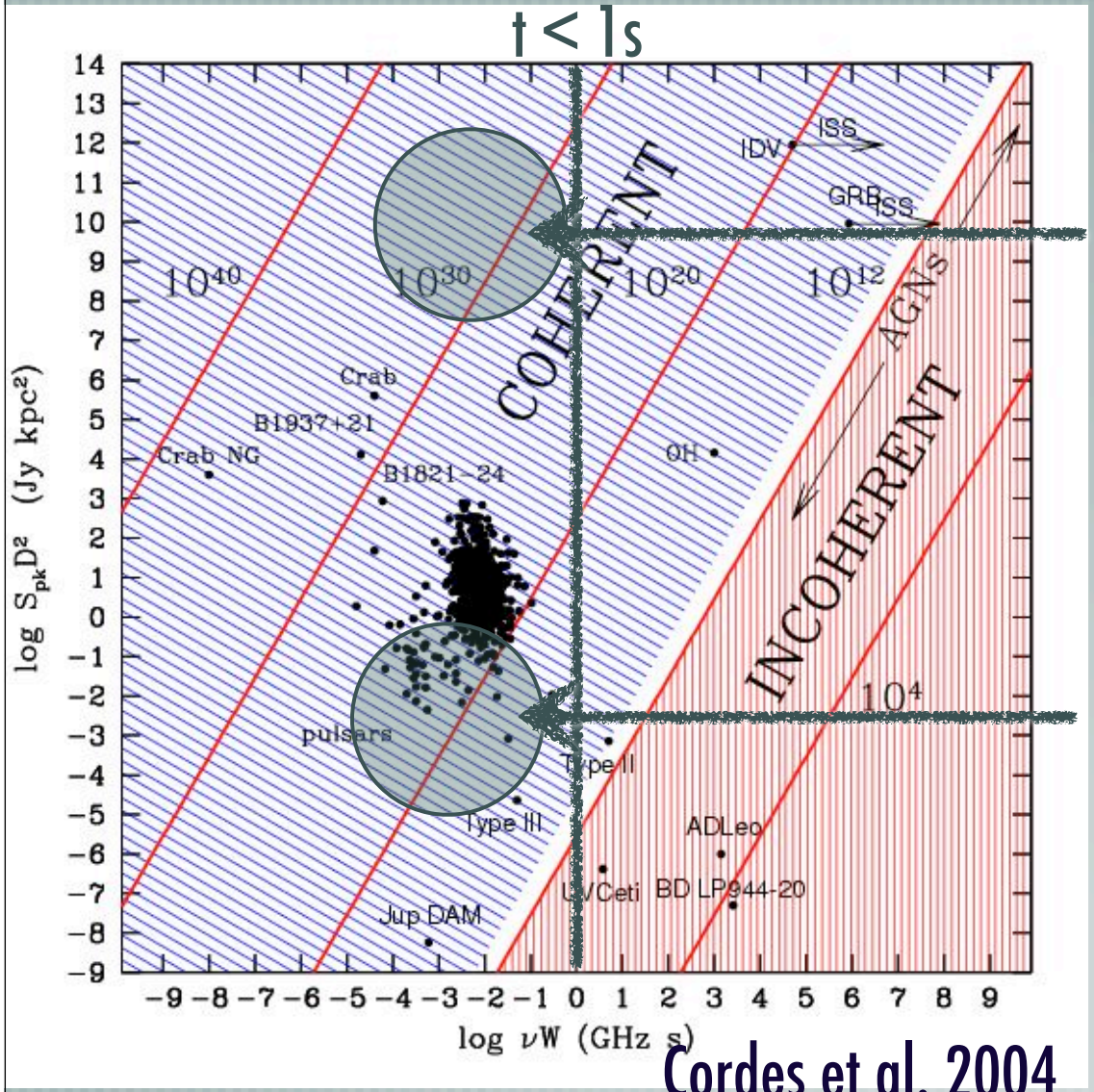


Cordes et al. 2004

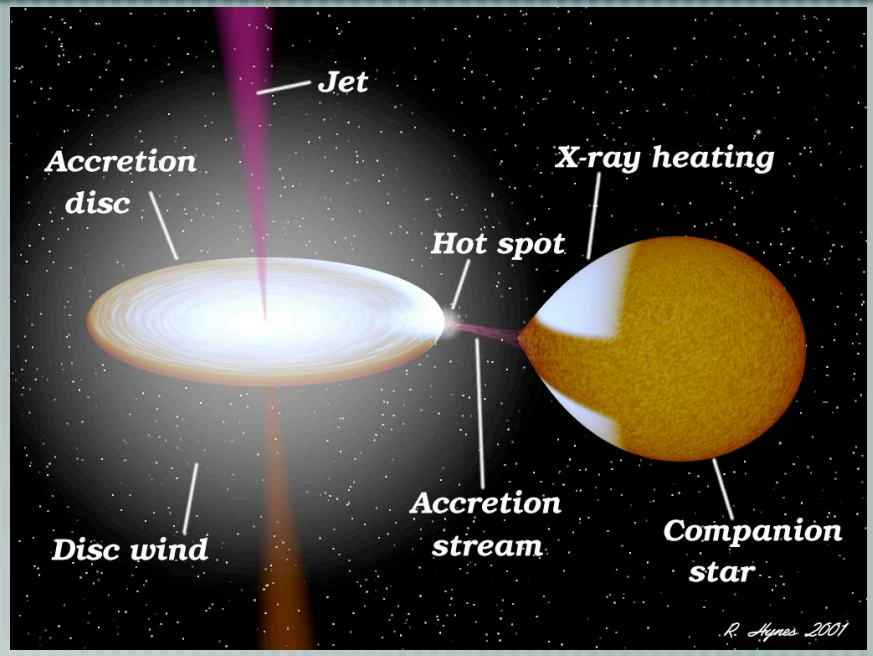
Rare and bright event, needs large FOV

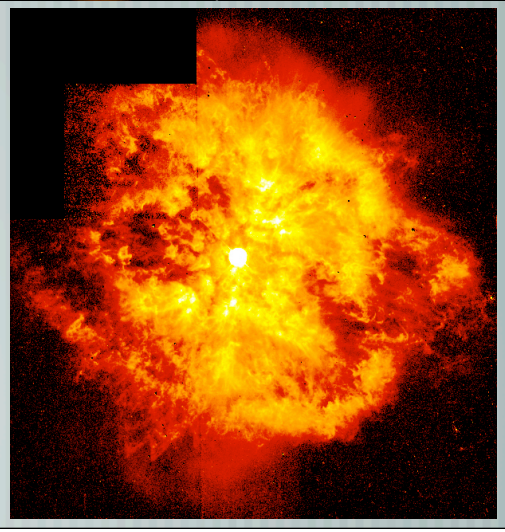
Weak transient event, needs high sensitivity

Slow transients

Slow Synchrotron Transients

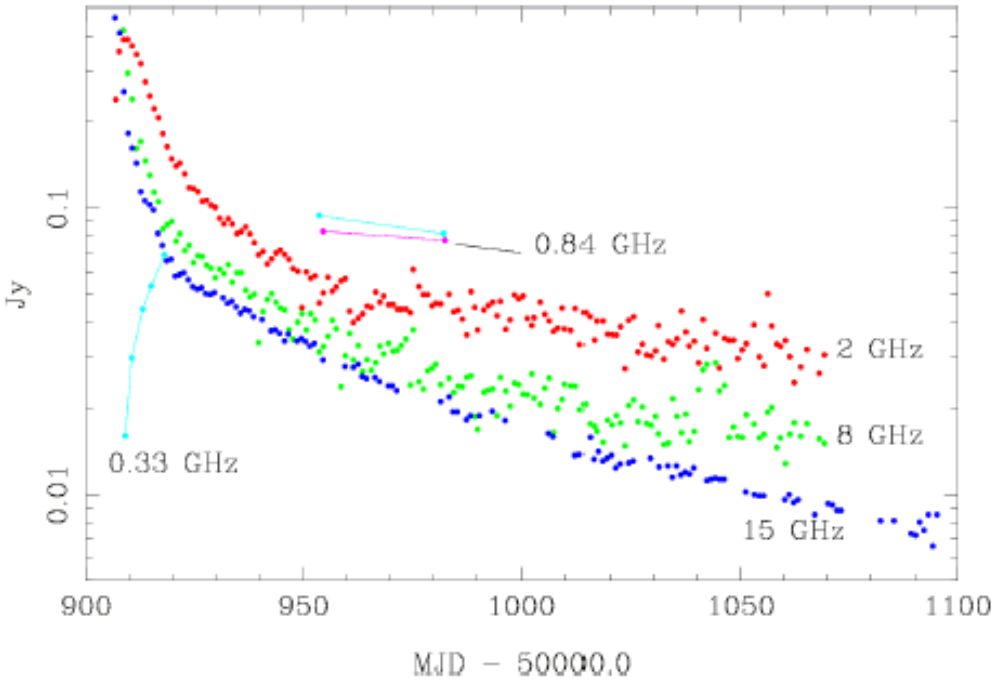
- Primarily explosive events or outflows
- Known source classes:
  - Cataclysmic Variables (CVs)
  - X-ray Binaries (XRBs)
  - Magnetar outbursts
  - Supernovae (SNe)
  - Active Galactic Nuclei (AGN)
  - Tidal disruption events (TDEs)
  - Gamma-ray bursts (GRBs)
  - Some novae (usually thermal)
  - **but do not forget the unknown !!**

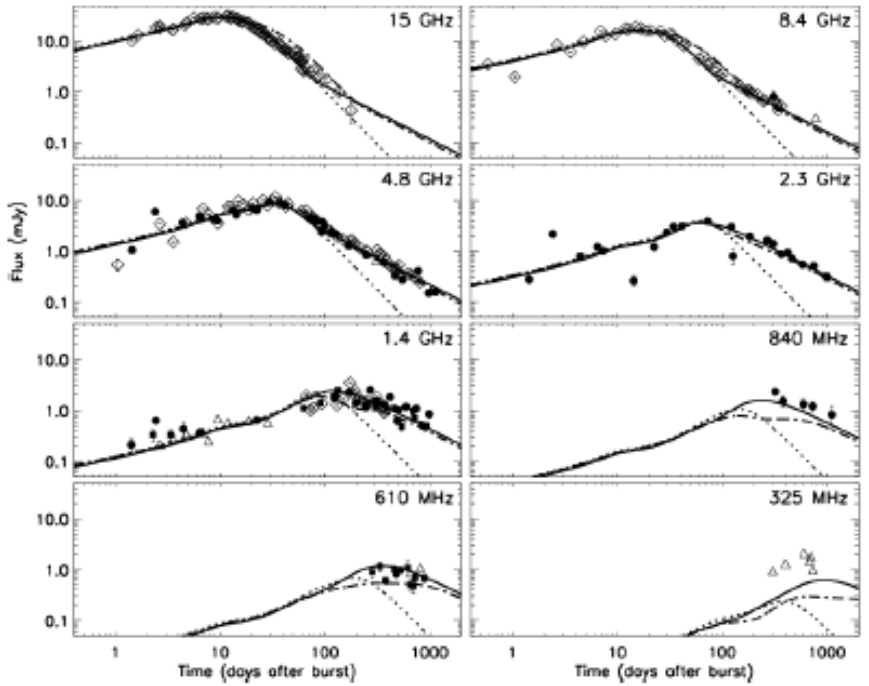




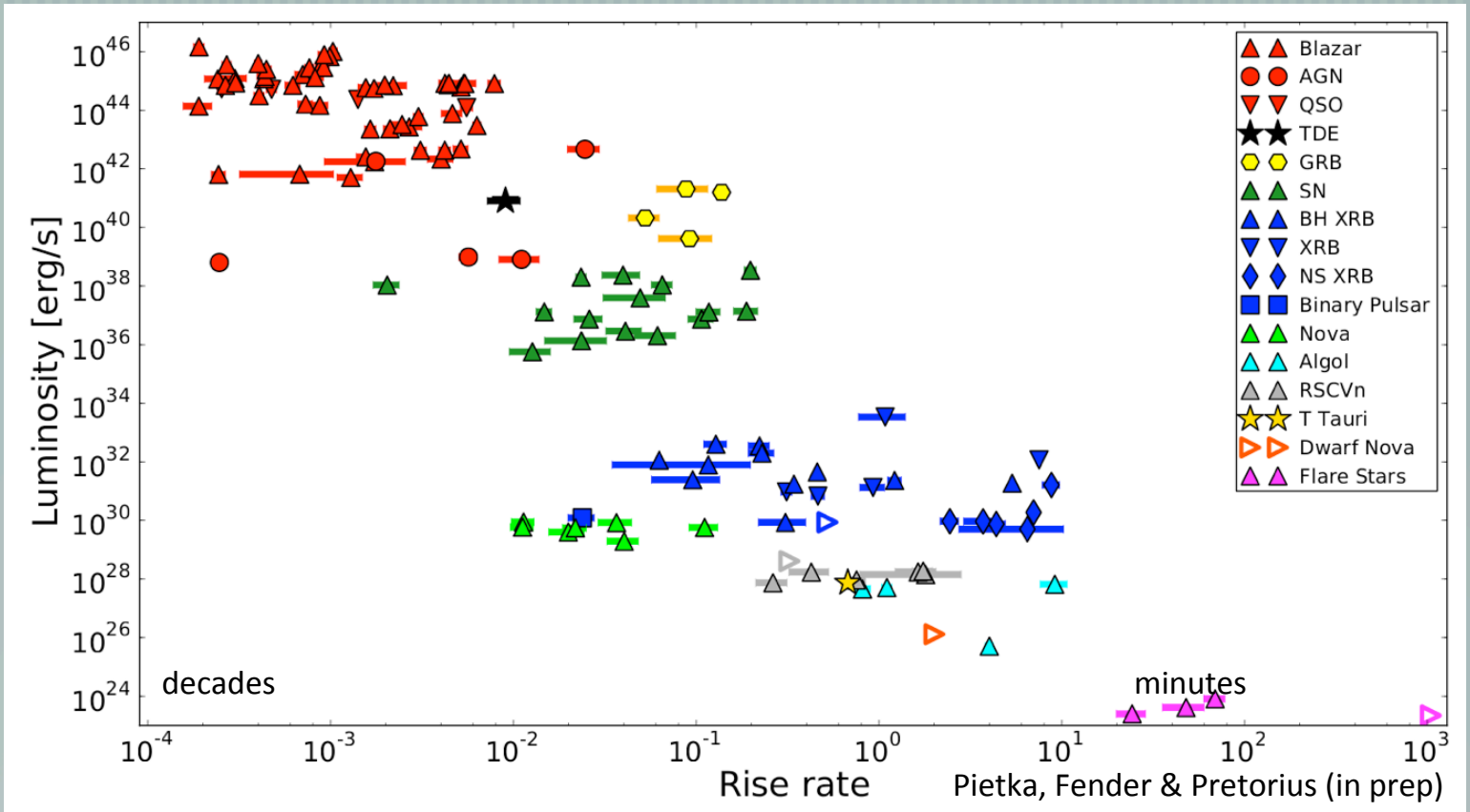
Typical evolution of a slow transient

- Shock-accelerated electrons and magnetic fields
- Important frequency evolution. Become optically thin later at lower frequencies (+lower flux also).



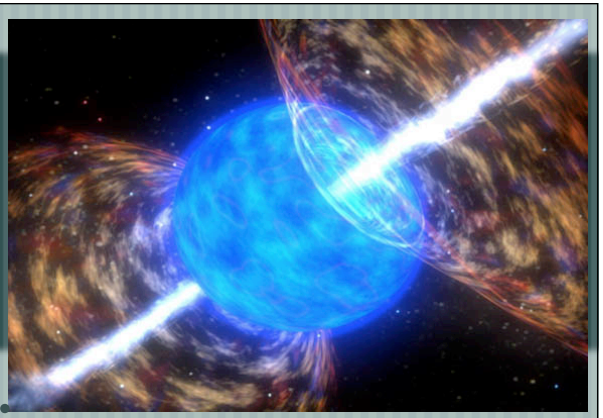


Similar physics along the mass scale

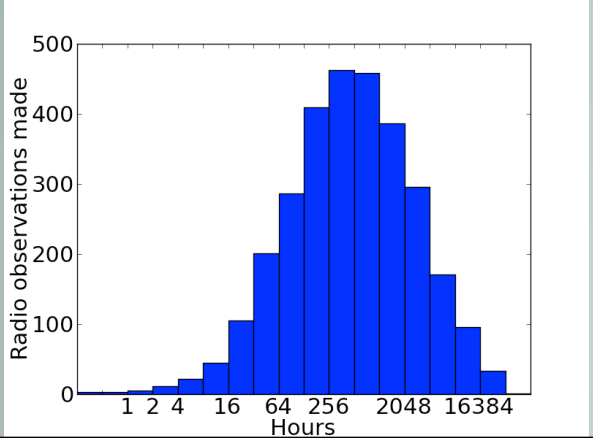


Measuring the kinetic feedback with transient cosmic explosions

Gamma-ray bursts



- Probes of distant Universe (could be seen to z~25!)
- Estimated rate 10^{-6} year^{-1} galaxy^{-1}
- Radio emission generated by afterglows
- Prompt emission likely self-absorbed at low frequencies



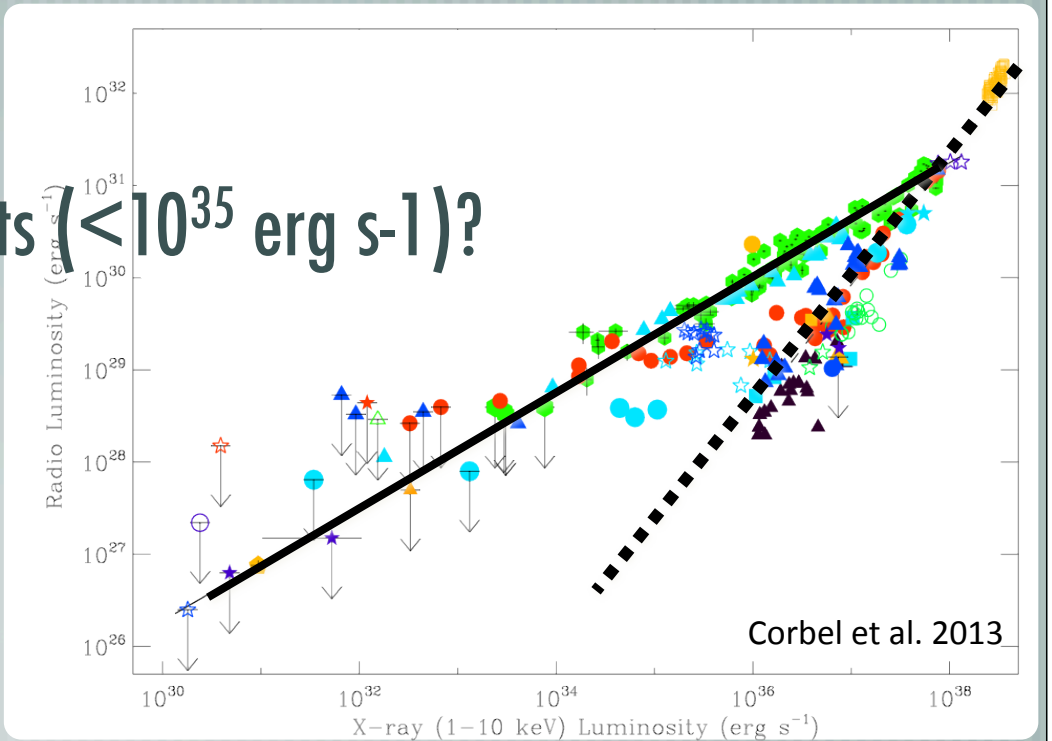
- Key questions:
  - Physical parameters
    - Kinetic energy of explosion
    - Density of circumburst medium
    - Outflow geometry
  - Orphan afterglows
    - Beaming fraction and total GRB rate
  - Radio loud vs radio quiet populations
    - 70% show radio emission, 30% do not

Tidal disruption events

- Star passing too close to a massive black hole
- Estimated rate 10^{-5} year^{-1} galaxy^{-1}
- Probe of jet physics
  - Launching mechanism
  - Super-Eddington accretion rates
  - Dense environments (cf AGN jets)
  - Possibly the most frequent synchr. transients (Frail et al. 2012)

X-ray binaries I

- Accreting black holes, neutron stars, white dwarfs
  - Do quiescent BHs host radio jets?
  - What fraction of the liberated accretion power do they carry away?
  - Broad-band emission ?
  - Nature of very faint outbursts ($<10^{35}$ erg s-1)?
- A few tens of outburst per year



SKA: probing a significant fraction of the whole outburst duration for almost all BHs in our Galaxy. All flaring transient BHs accessible in the local Universe (possibly also up to Virgo @ 15 Mpc)

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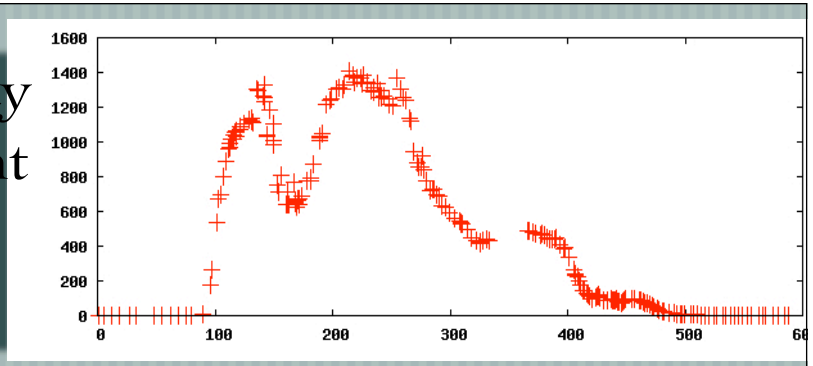

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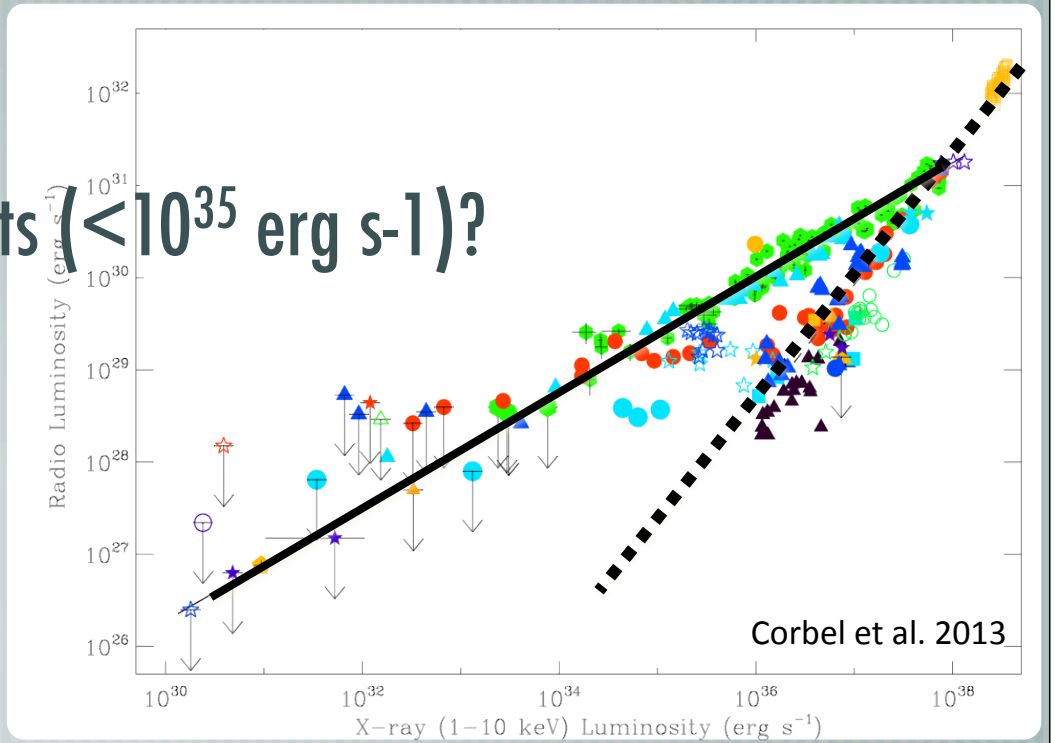
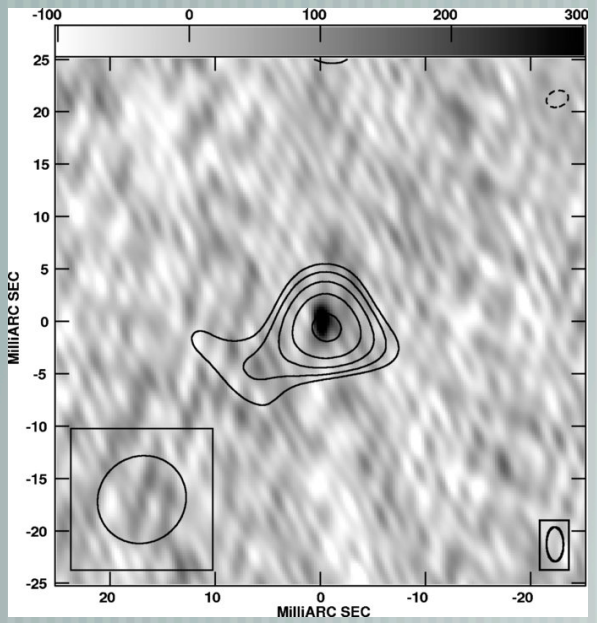


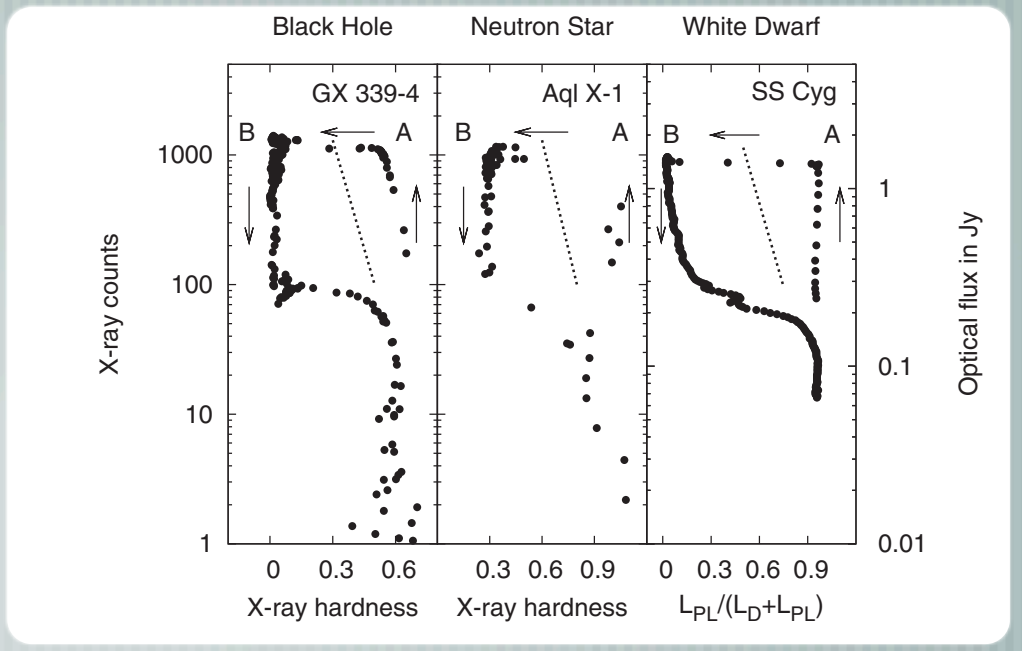
SKA: probing a significant fraction of the whole outburst duration for almost all BHs in our Galaxy. All flaring transient BHs accessible in the local Universe (possibly also up to Virgo @ 15 Mpc)

X-ray binaries II

- NSs and WDs: Is the accretion-ejection coupling universal?
- How does jet launching depend on depth of potential well, presence of a stellar surface/magnetic field?



Miller-Jones et al. 2010

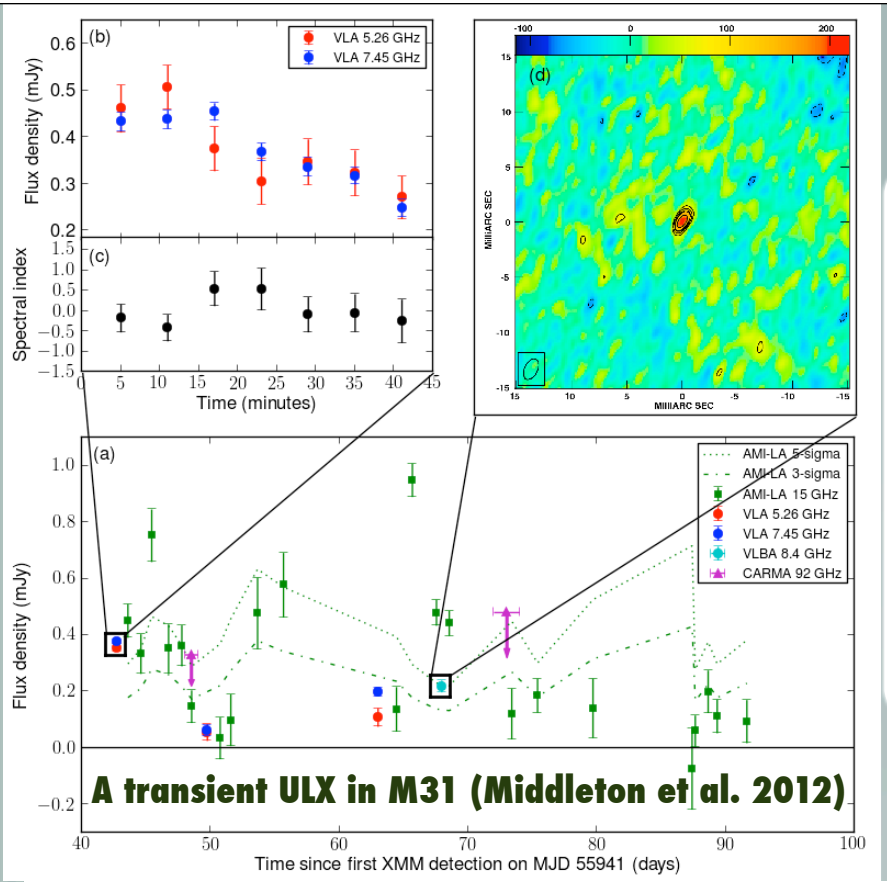


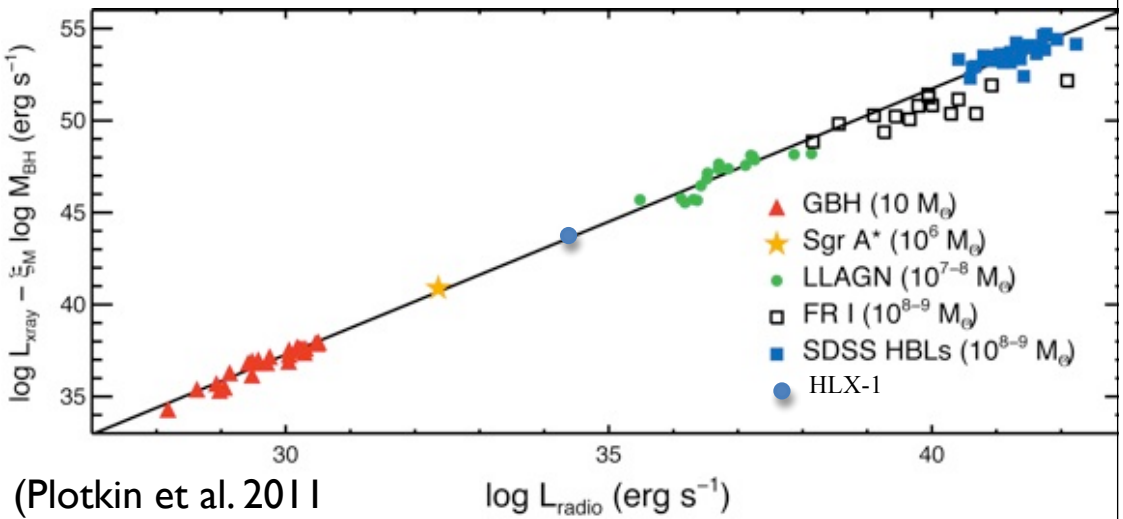
Koerding et al. 2008

Ultra-luminous X-ray sources

- X-ray Luminosities $>1.3 \times 10^{39}$ erg s^{-1} (Eddington limit for a 10 $M_\odot$ BH)
  - Are these stellar-mass BHs accreting at/above Eddington?
  - Is there evidence for massive BHs (HLX-1 with L_X Max $\sim 10^{42}$ erg s^{-1})?
  - Fundamental Plane to get BH masses
  - Probe accretion and ejection at Eddington rates
  - Growth of quasars in early Universe
  - Feedback effect on surroundings (EoR)
  - Needs sufficiently high resolution

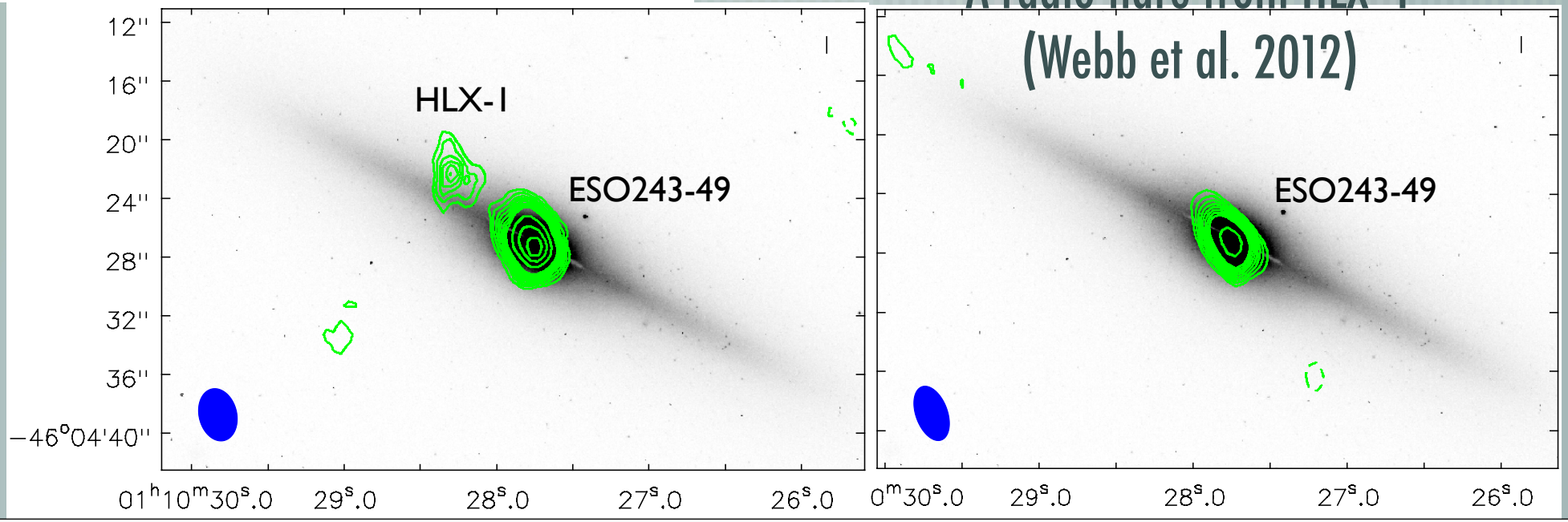
Bridging the gap in mass scale ?





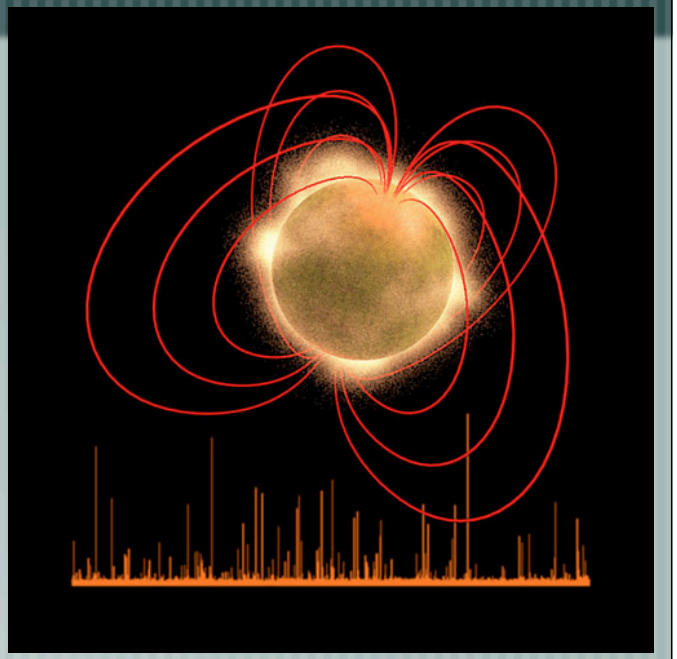
(Plotkin et al. 2011

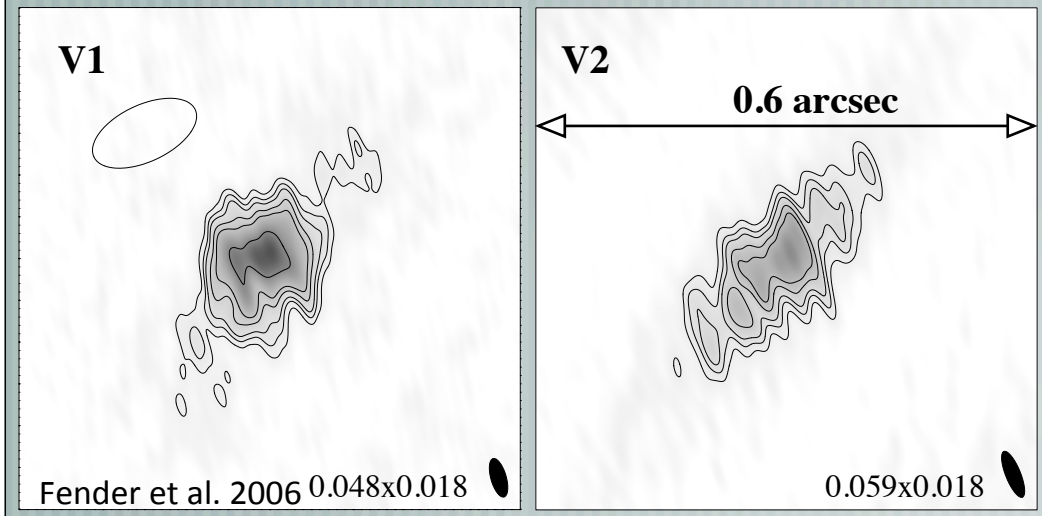
A radio flare from HLX -1 (Webb et al. 2012)



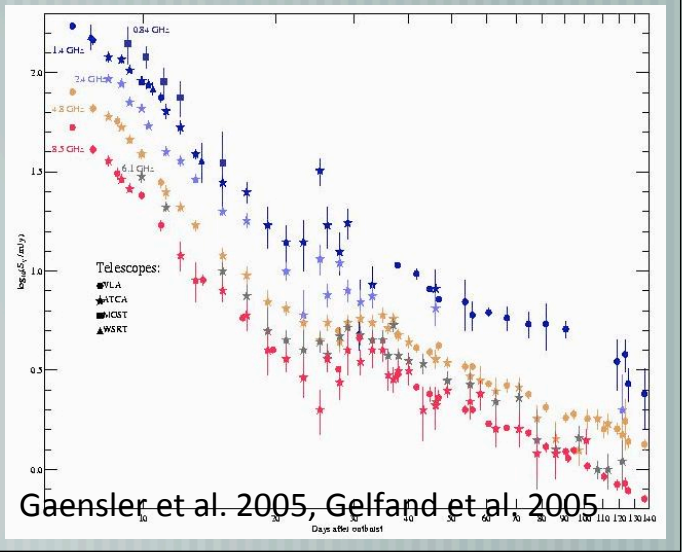
Magnetar giant outbursts

- Explosive injection of energy into ambient medium following rearrangement of B-field
  - Bright synchrotron flares (SGR1806-20)
  - Collimated outflows
  - Probing magnetar giant flare up to 300 kpc.



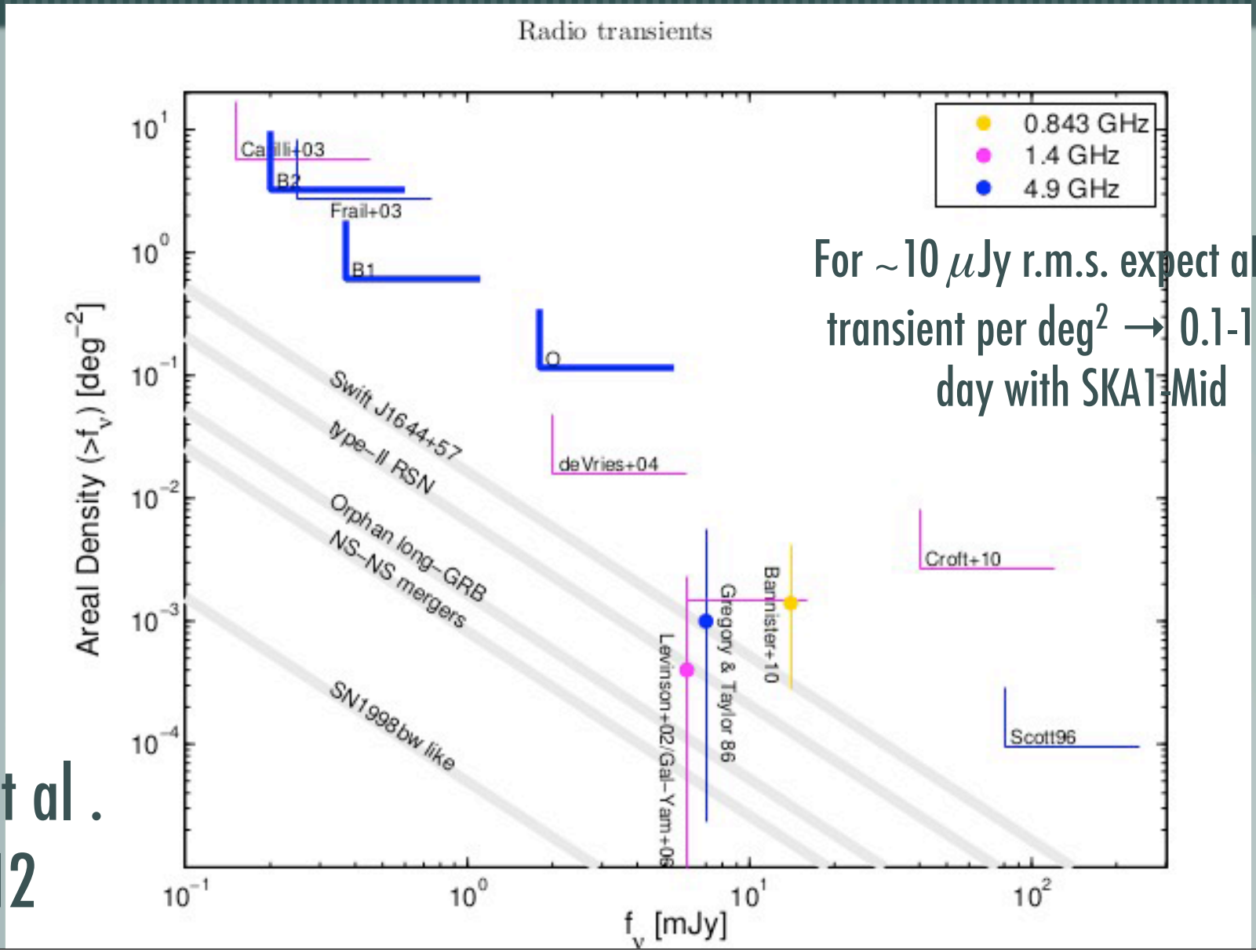


Fender et al. 2006



Gaensler et al. 2005, Gelfand et al. 2005

Transients in the SKA era

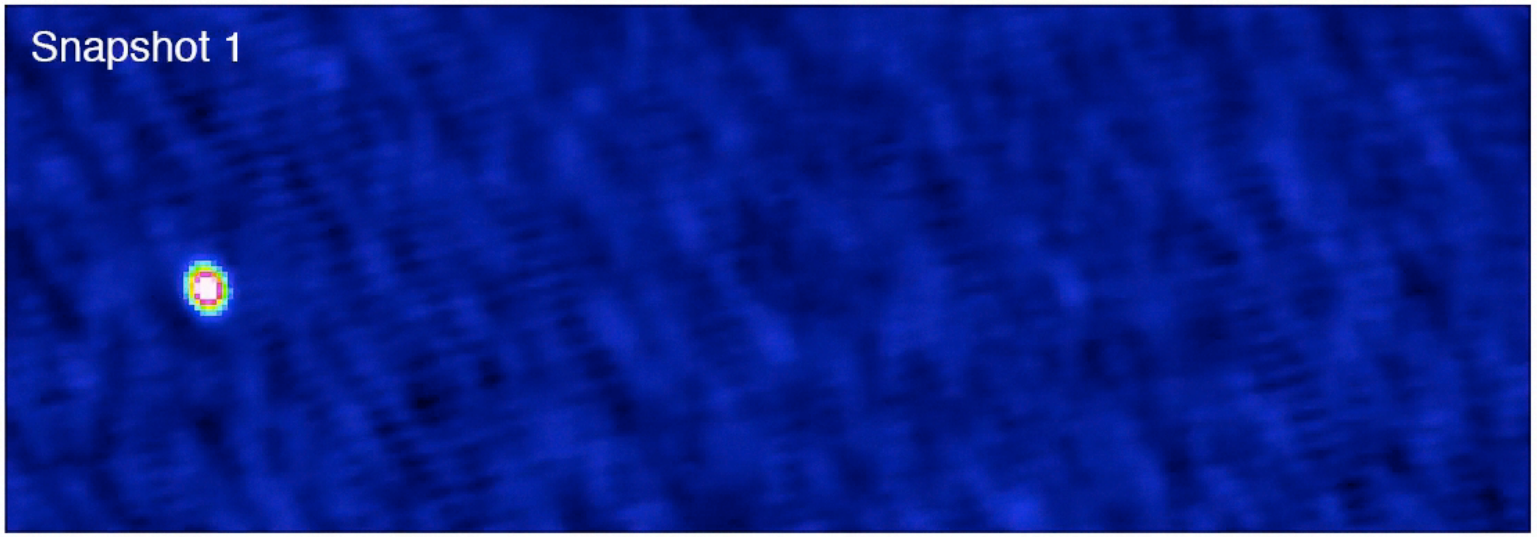


For ~10 μJy r.m.s. expect about 1 transient per deg^2 → 0.1-10 per day with SKA1-Mid

Frail et al . 2012

First Lofar Transients with MSSS

First MSSS(-LBA) transient candidate (Stewart et al, in prep)



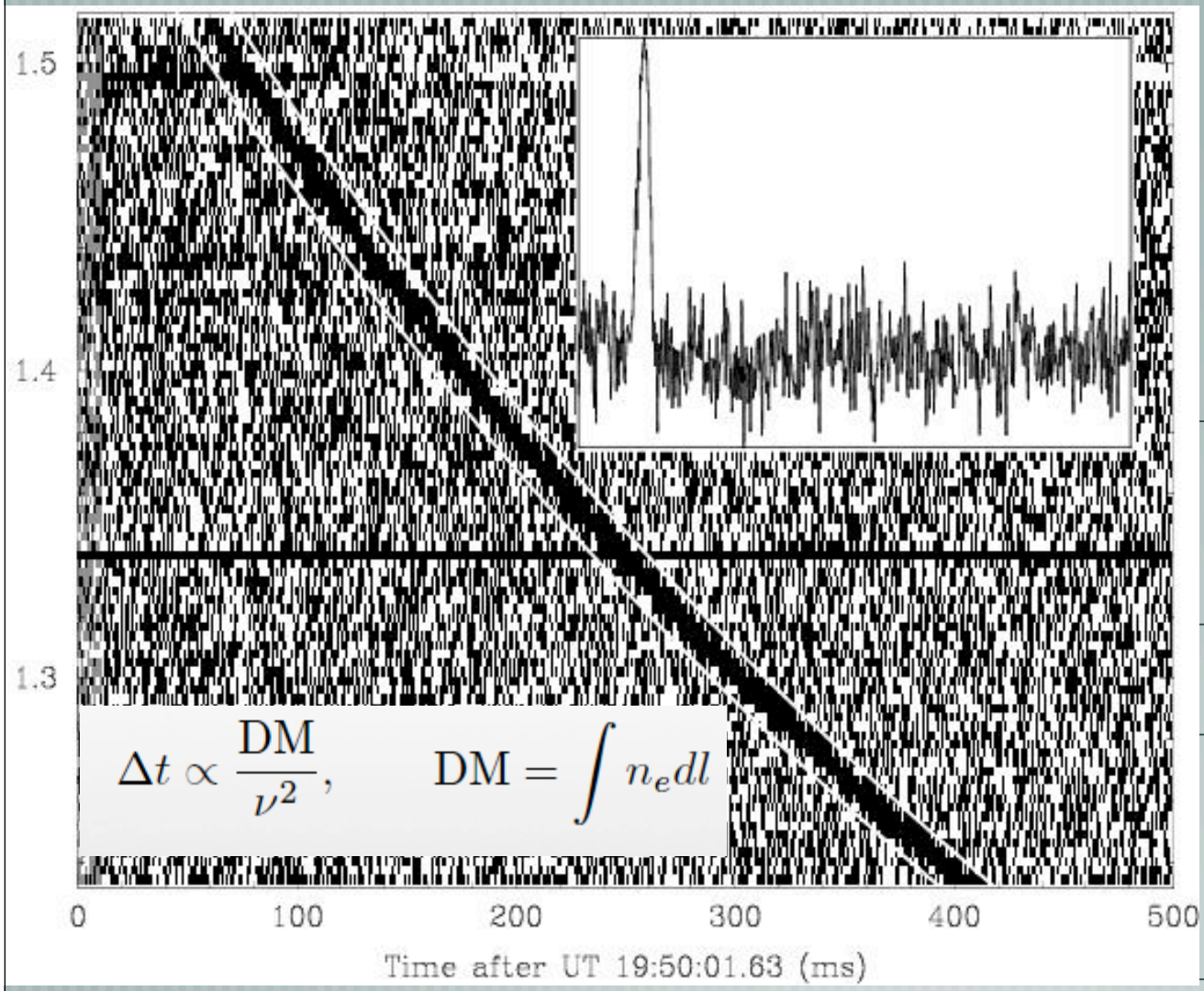
- Appears in one 11-min snapshot, using 10 σ threshold of 4 Jy
- Implied rate for Δt=11min is 1/2537 transients day^{-1} deg^{-2} (~1 transient per square degree per 7 years!)

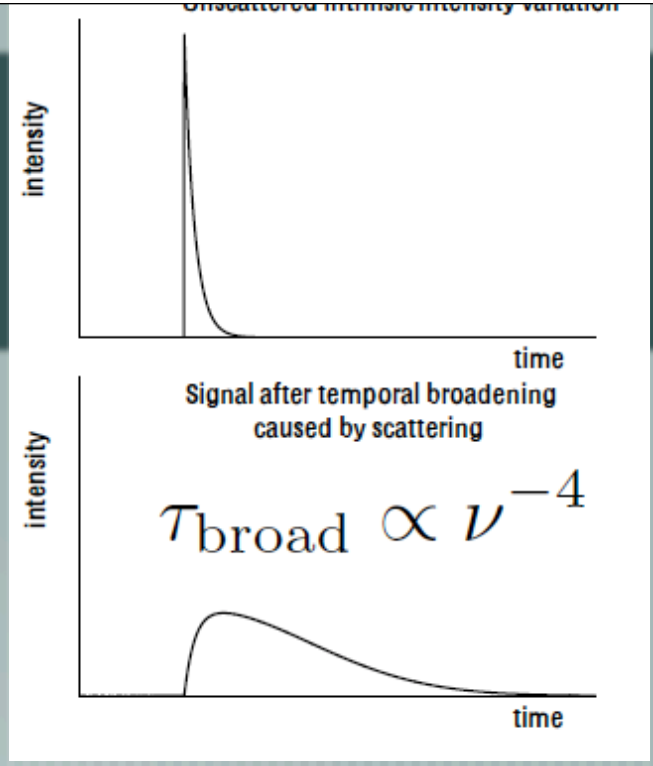
Fast transients

Types of fast transients ?

- Pulsar giants pulses, RRATs and magnetar
- SETI event
- Electromagnetic counterpart of GW event
- Exoplanets, flare stars, solar bursts
- Unknown event ?
- Fast radio bursts (FRB): aka Lorimer type burst
- FRB = Good probe of the IGM (missing baryons problem)
- FRB as a cosmic rulers (measure dark energy eq of state param. «w» at z >2)

The Lorimer burst

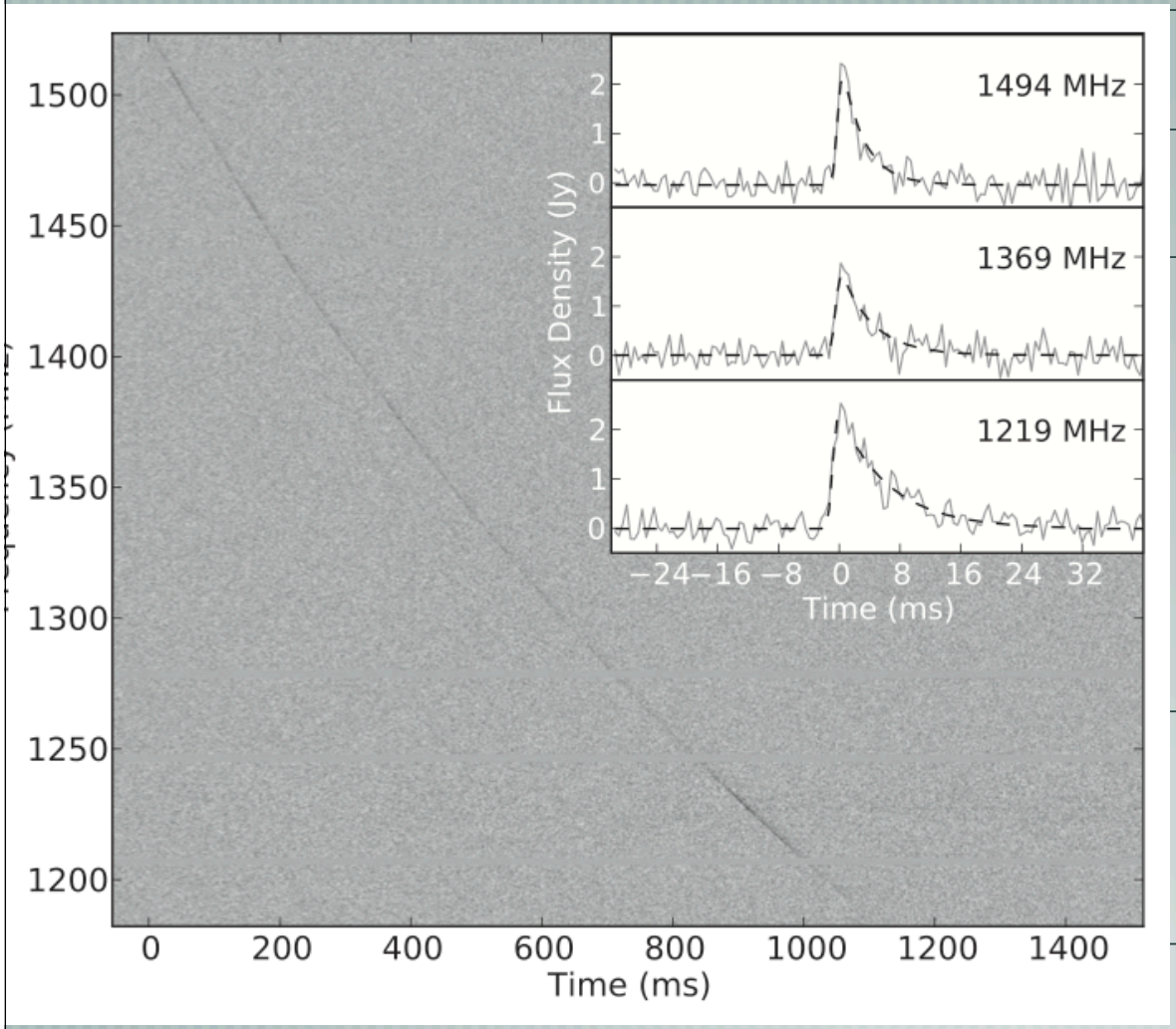




- A 30 Jy highly dispersed burst
- Duration ~ms
- High DM > Galactic ⇒ 1 Gpc
- No repetition

Lorimer et al. 2006

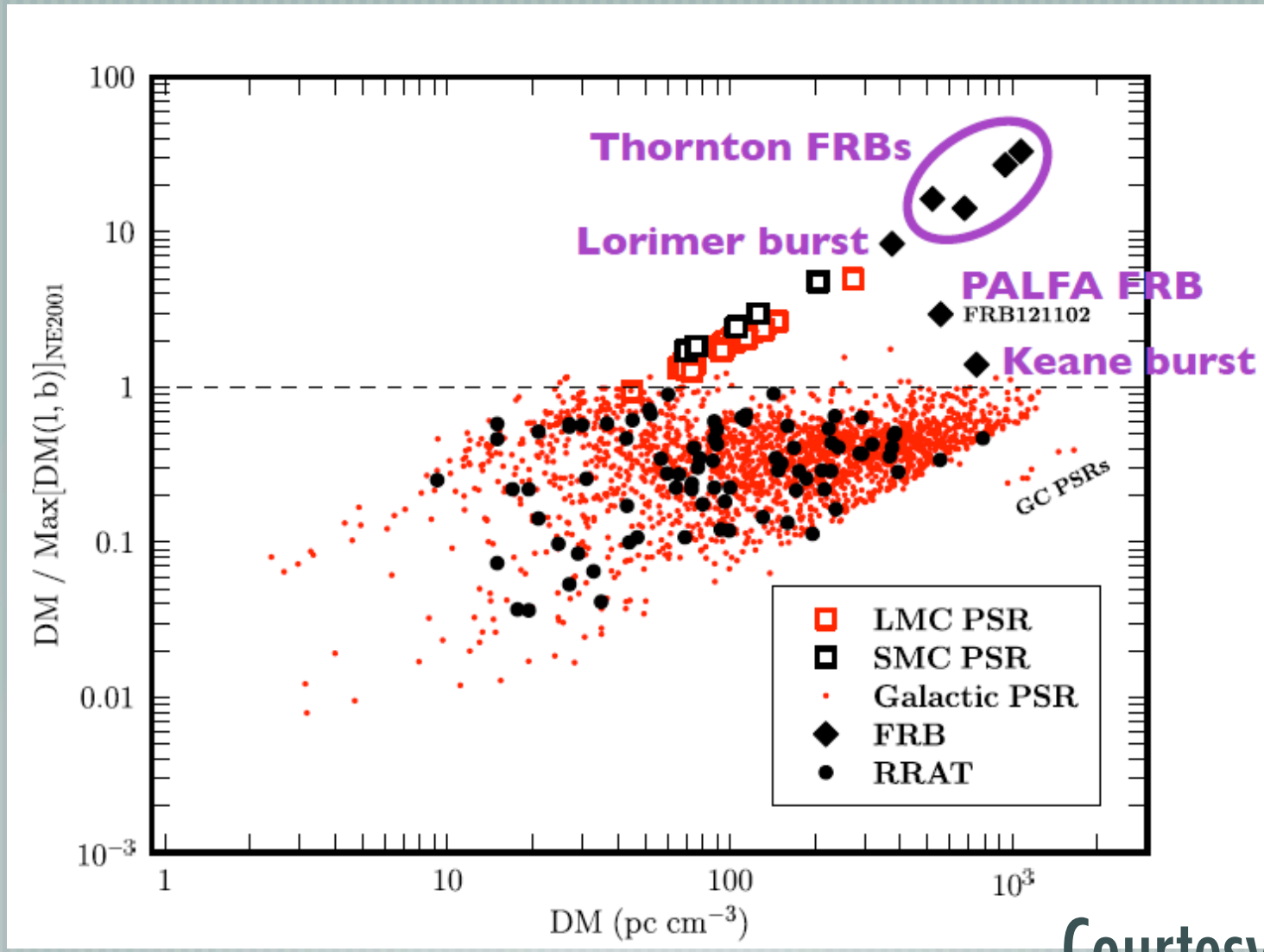
New FRBs



Thornton et al. 2013

- FRB 110220
- DM = 944 pc cm^{-3}, z~0.8
- Pulse width increases as $\nu^{-4.0}$, consistent with scattering in a turbulent plasma
- 14 such events now (not only Parkes) !
- **Rate : 10 000 / sky / day !!!**

Some of the detections



Courtesy: J. Hessels

What are there ?

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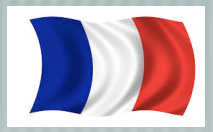
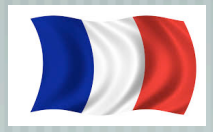
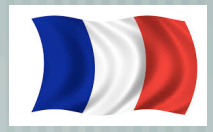
- Rapid change, means , small emitting area
- Blitzars ? Collapse of a NS to a BH ?
- BHs collision ? Counterpart of a GW event ?

Getting involved in transients

- LOFAR Transient KP: All kind of transients: pulsars, slow transients, exoplanets, ... 
- MeerKAT: ThunderKAT  + TRAPUM 
- ASKAP: VAST  + CRAFT
- And the, SKA1
- Get in touch with me if interested

Conclusions

- A variety of synchrotron transients with key questions on the extreme Universe: black holes, relativistic jets,...
- New fast transients. SKA1: a FRB factory !!
- Electromagnetic counterpart of a GW event
- Probing the distant Universe
- Do not forget the unknown, i.e. unexpected discoveries by opening new parameter space in the time domain with superb sensitivity.
- A lost of synergies with forthcoming MW facilities (e.g. LSST: millions of transients per night !!)